Analysis of Flare Events Associated with Slowly Positively Drifting Bursts Observed at 800 – 2000 MHz Range

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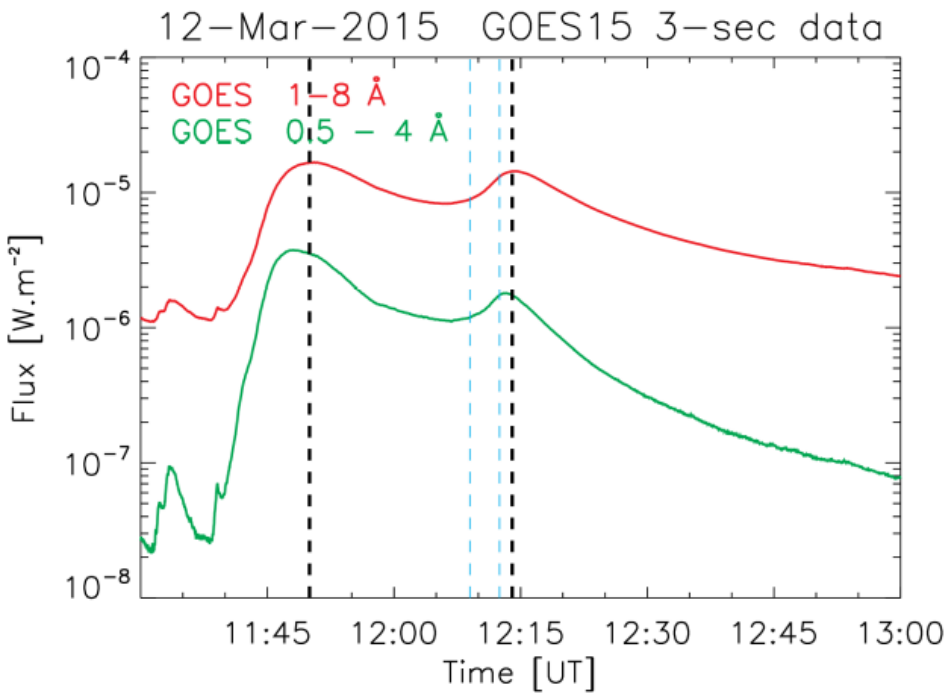
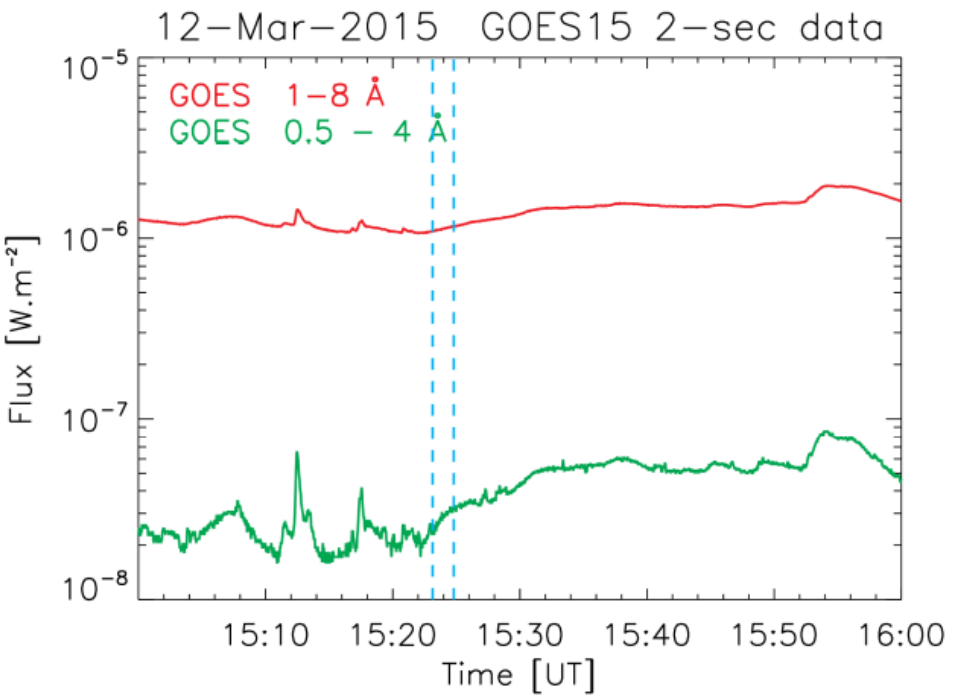
We have analysed two flare events on 12-Mar-2015 A - M1.4 flare SOL20150312T12:14:00 and B - a ‚flare-like event' with the rise of GOES SXR flux ~ C-class flare level

Event A

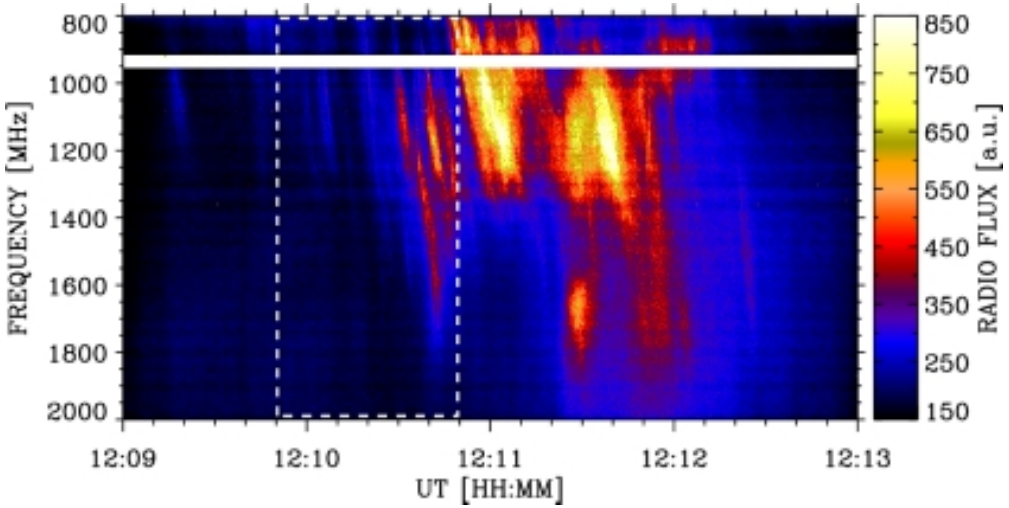


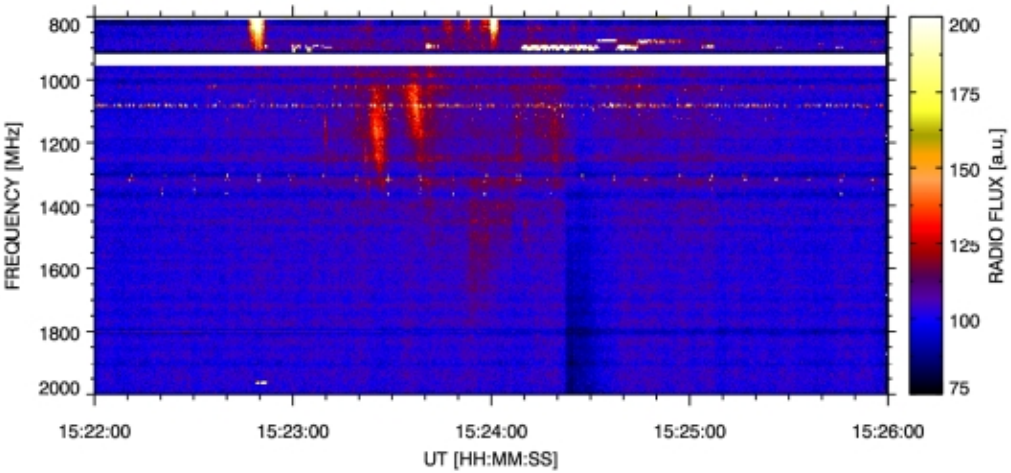
Event B



Blue dashed lines show time interval when SPDBs were observed and black dashed lines mark the maximum of the flare in GOES SXR flux. For the Event B, no flare was reported according to GOES SXR flux.

Events A and B were associated with Slowly Positively Drifting Bursts (SPDBs) as can be seen on spectra from Ondřejov radiospectrograph





Event A – group of SPDBs during 12:10:20 - 12:12:30 UT

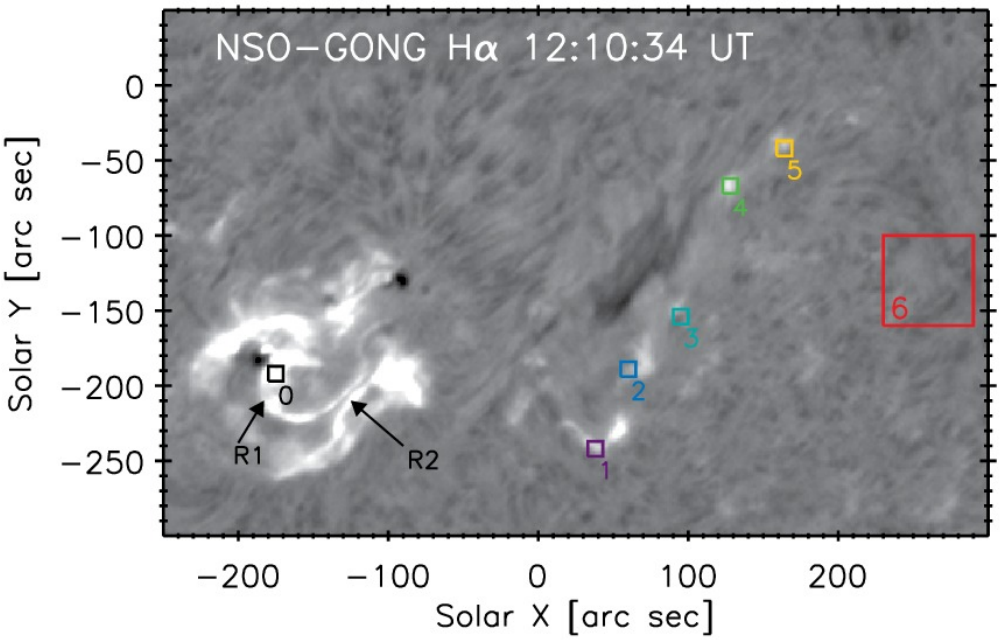
Event B - had 2 weak SPDBs during 15:23:23 - 15:23:38 UT

SPDBs are rarely observed. They are similar to RS type III; the burst proceeds from lower to higher frequency, and its frequency drift is less than ~300 MHz/s. Their origin is unknown.

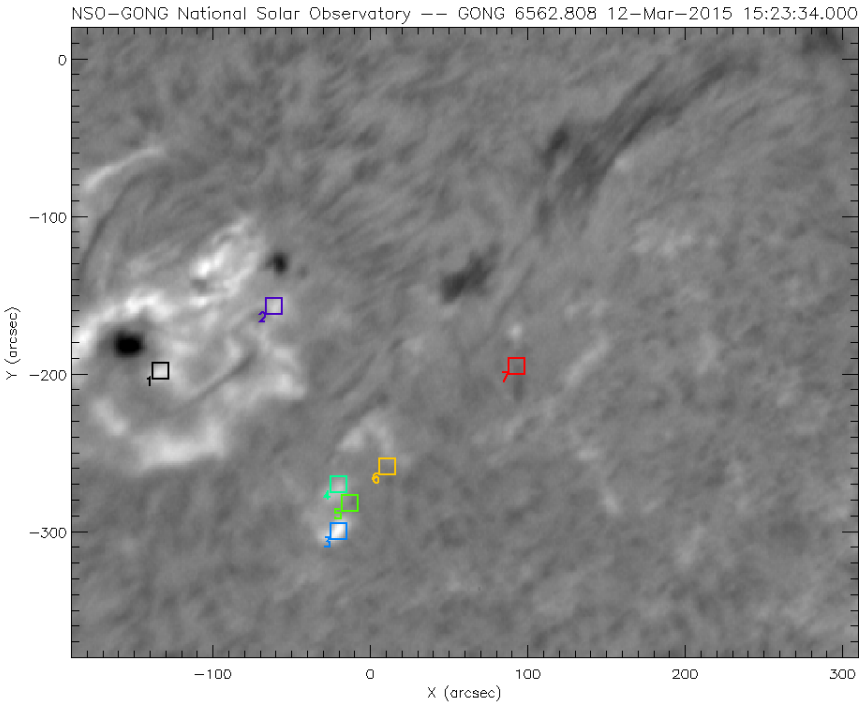
Imaging observations vs. SPDBs

- **We have no spatial information about the location of radio source from the spectrum therefore we turned to investigate the origin of SPDBs by following the evolution of the flare and searching for any exceptional phenomena**
- **Both events occurred at the southern part of AR 12 297 and involved actvity of the large filament located westward from AR**
- **For both events flare brightenings (coloured squares) started to appear in AR but also simultaneously along the filament visible in H-alpha (images from NSO-GONG).**

Event A

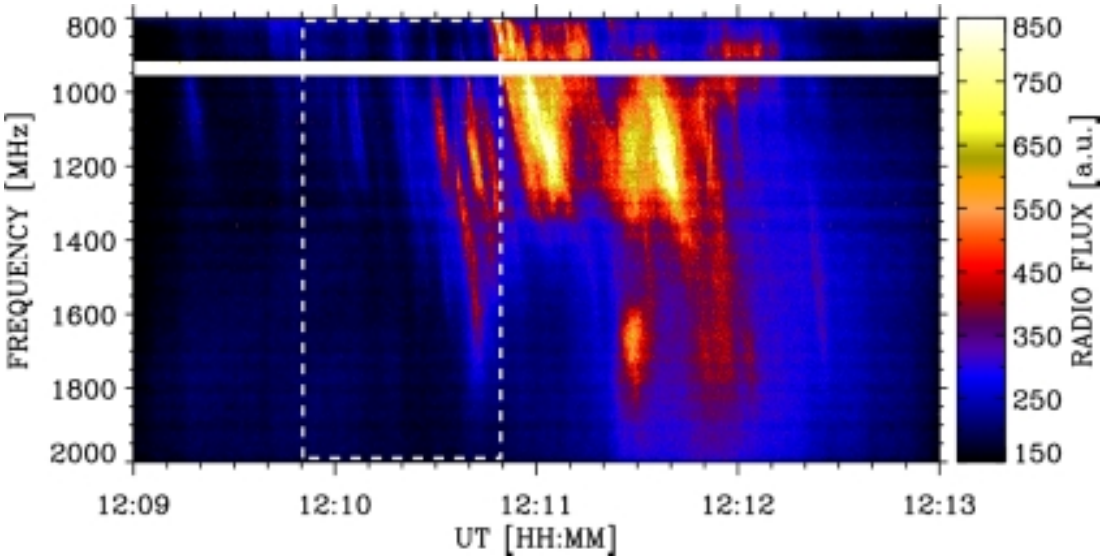


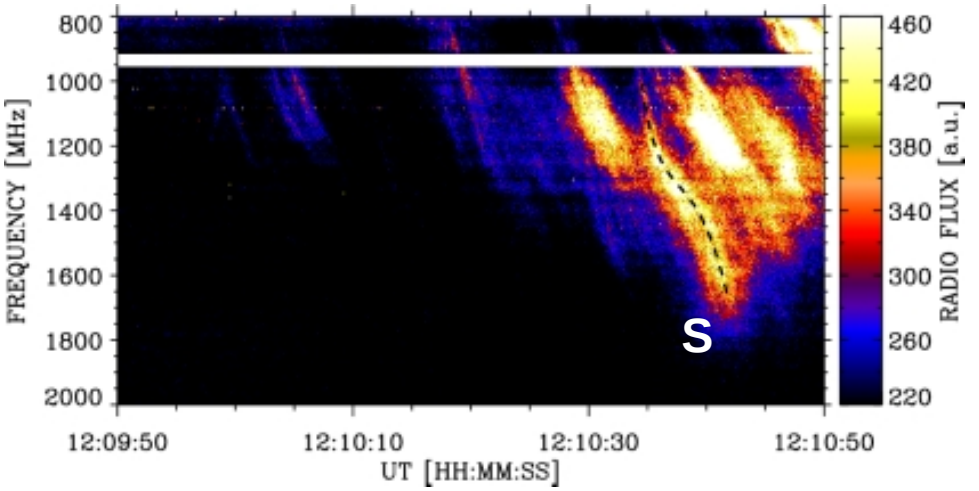
Event B

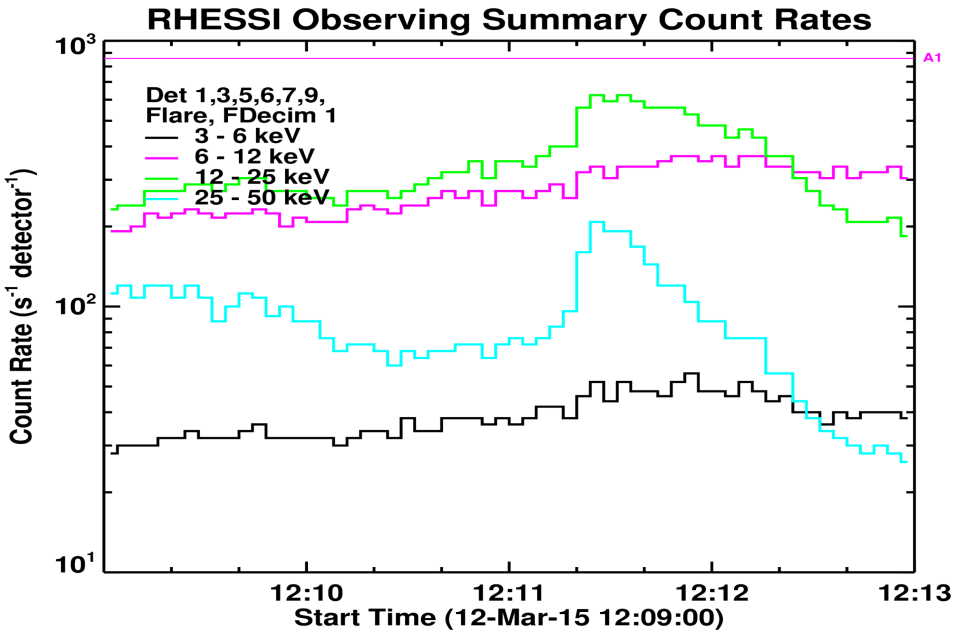


Event A - M1.4 flare SOL20150312T12:14:00

(Zemanova et al., ApJ 905, 2020)

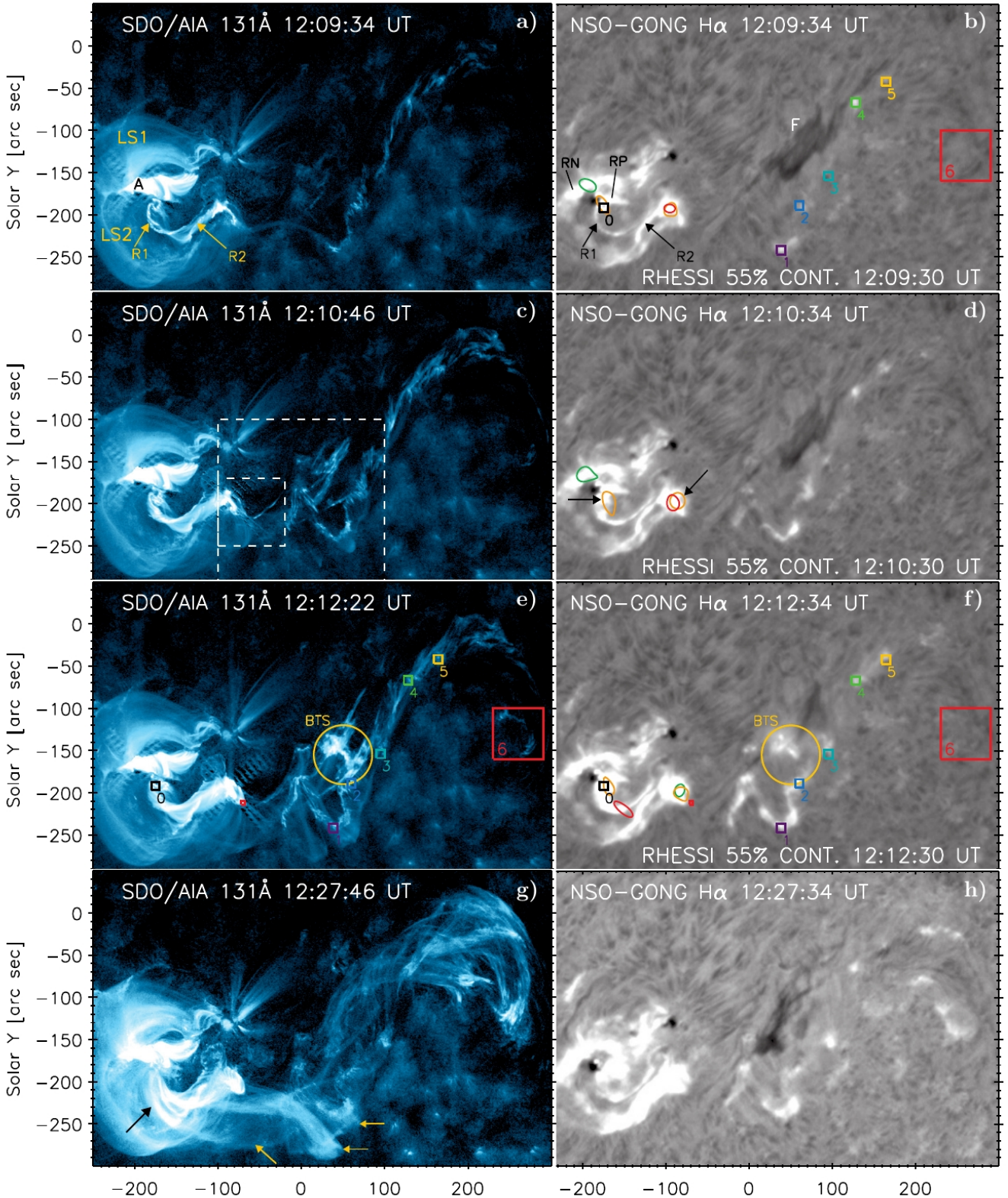






SPDBs were observed during the impulsive phase of the flare: 12:09:00-12:12:30 UT, in 800-2000 MHz range, frequency drift 45-100 MHz/s

The most interesting burst was curved SPDB (S-like shape) - Burst S – 12:10:34-12:10:41 UT, range 1000-1700 MHz, duration of 7s, frequency drift ~100 MHz/s.



- **12:08:00-12:12:30 UT J-shaped ribbons R1 and R2 appeared and evolve at the South of NOAA AR 12 297**
- **Simultaneously, several brightenings started to appear along the filament F**
- **A small cusp was formed at the tip of the hook of R2**
- **Plasma was ejected from the region top of the cusp towards F**
- **Above the F the Bright Transverse Structure (BTS) formed**
- **Late gradual phase (12:27:40 UT) - activated filament – changes of its appearance**

Event A - The cusp and plasma ejection – signs of magnetic reconnection observed during the Burst S 12:10:34-12:10:41 UT

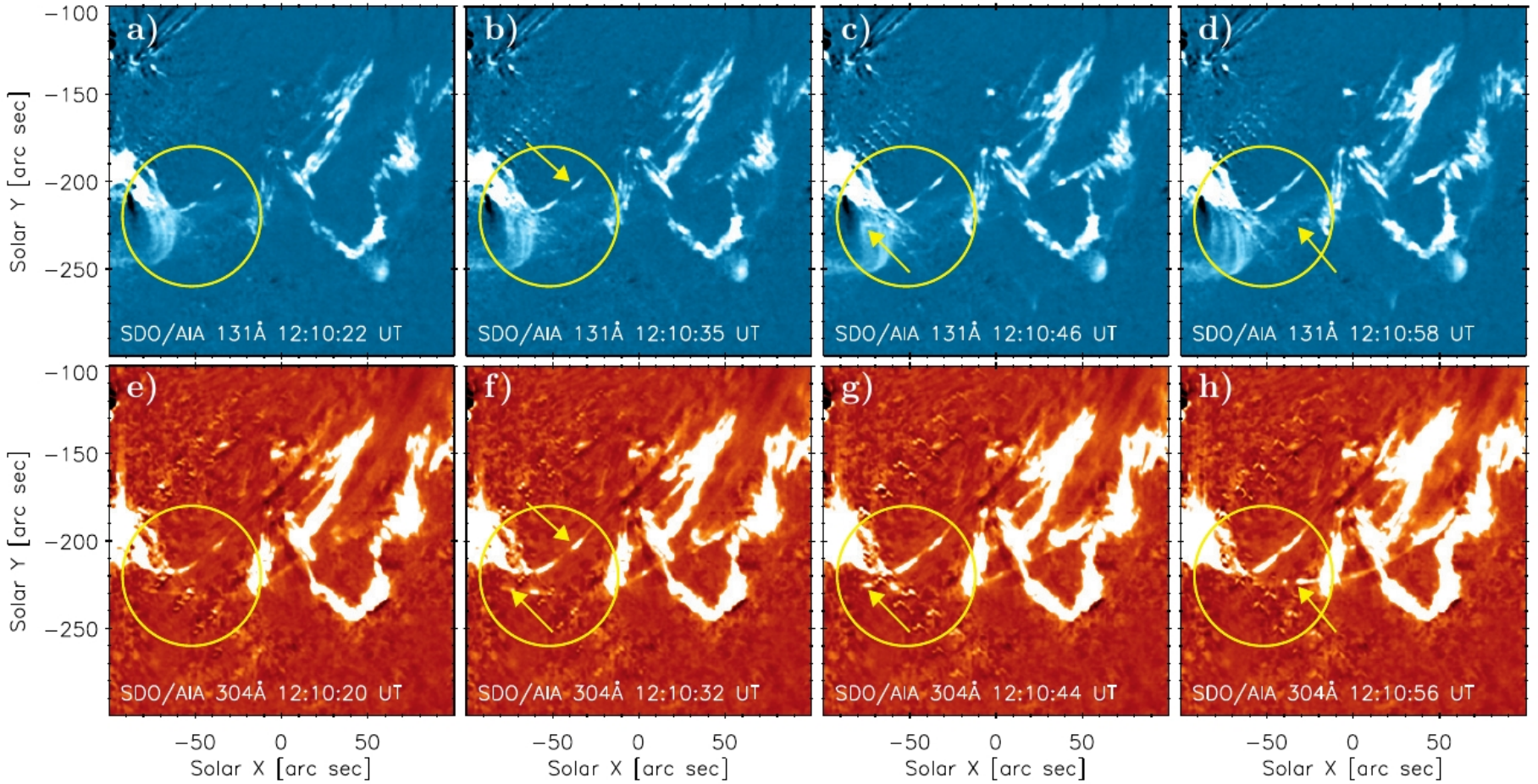
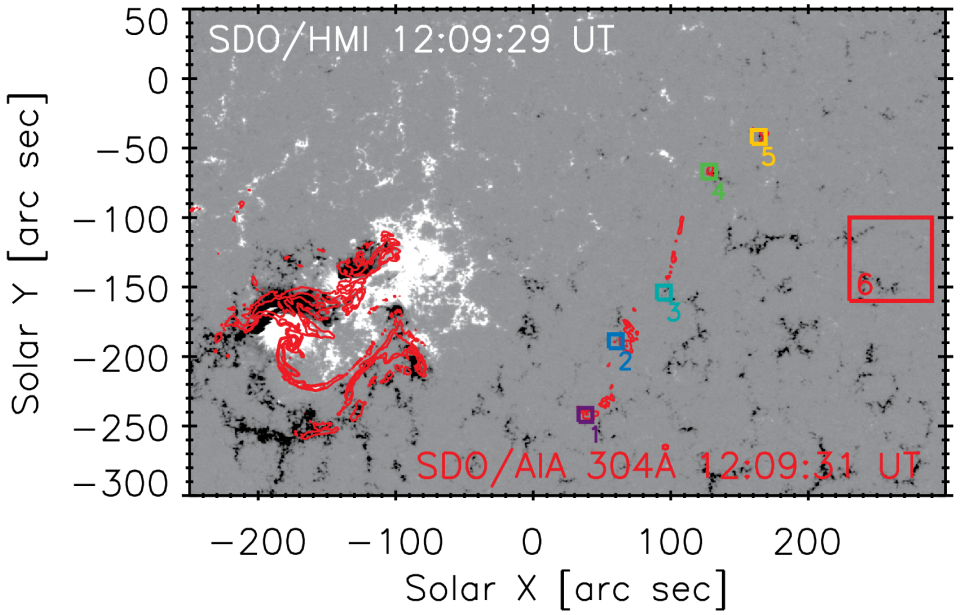
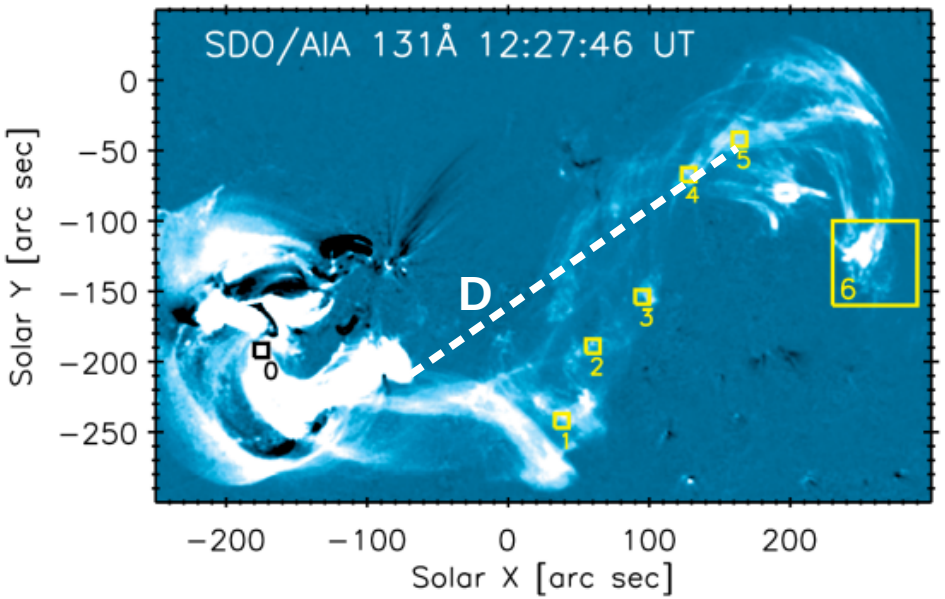


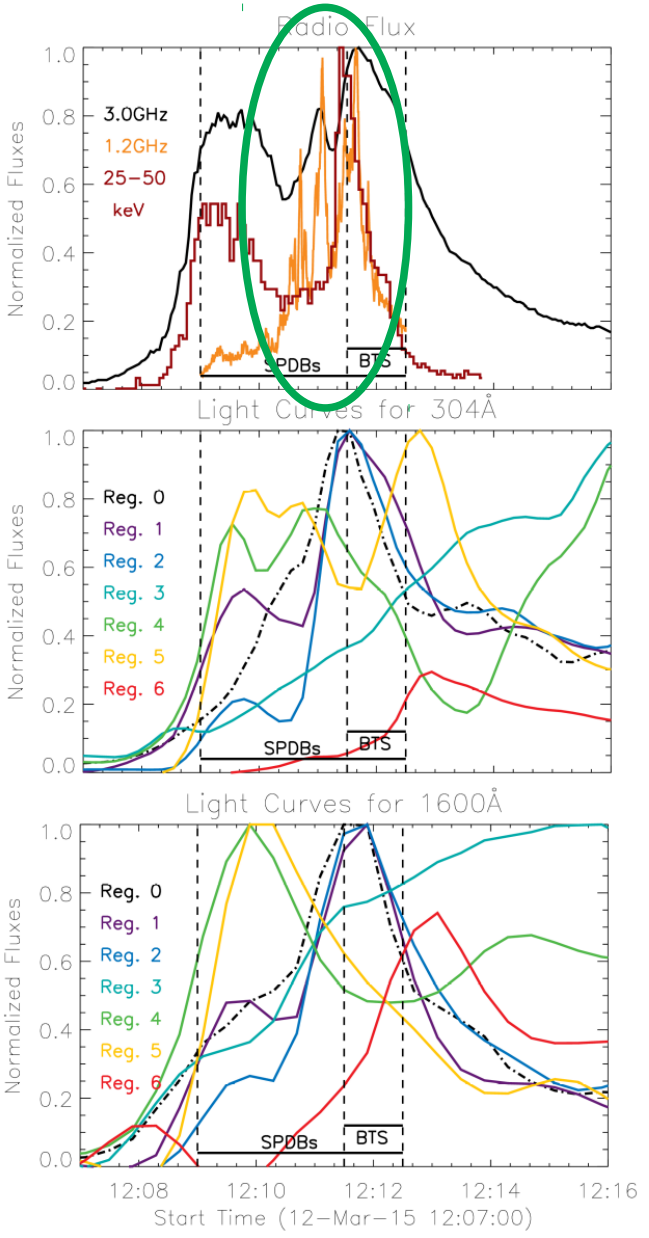
Figure 5. Detail of the cusp and plasma ejection during the burst S. (a)–(d) Base difference images in *SDO*/AIA 131 Å filter with a base image at 11:30:10 UT. (e)–(h) Base difference images in *SDO*/AIA 304 Å filter with a base image at 11:30:08 UT. For explanation see Sec. 3.2.1.

Event A - Light Curves – from brightenings along the filament

The main phase of SPDBs was observed at 12:10:20–12:12:30 UT



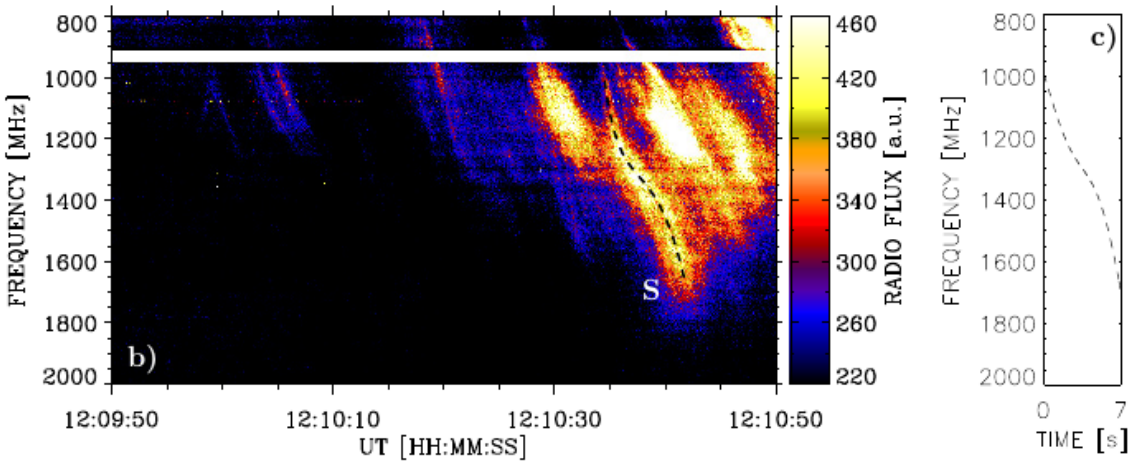




Event A – The estimate of an agent velocity responsible for S-like SPDB

- **Burst S – 12:10:34-12:10:41 UT, estimated velocity – observed frequencies and Aschwanden (2002) model of density in solar atmosphere - 2040 km/s (1st harm.), 3650 km/s (2nd harm.) - slow for (RS) type III; using the distance D, between the cusp and Region 5, and the burst duration of 7s, we obtain v = 30 000 km/s**

- **EUV images – 12:10:00-12:12:30 UT – cusp, plasma ejection, BTS – magnetic reconnection – We proposed that the beam propagates from the cusp region through filament which is nearly horizontally oriented in solar atmosphere and modelled the S-like shape of the burst (Fig. c)**



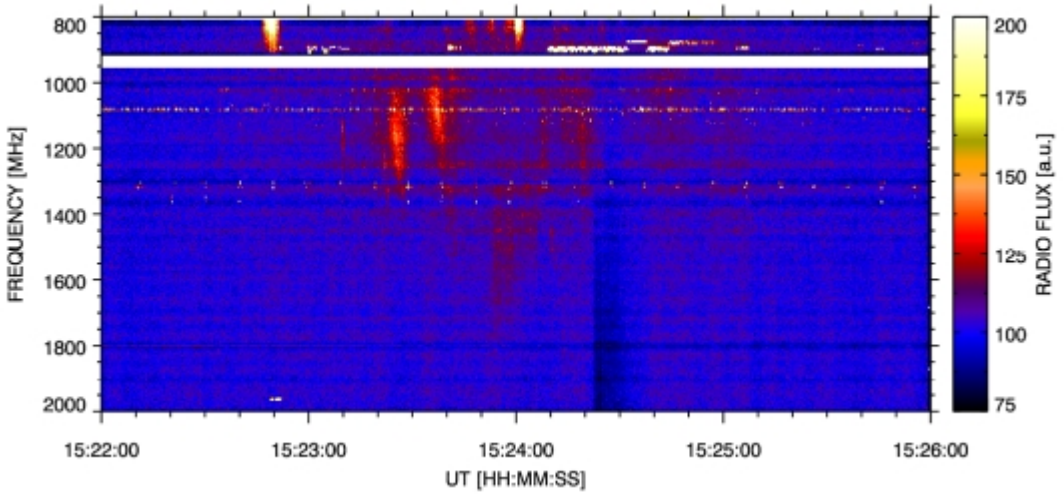
Case	T (K)	Height scale H_s (km)	$v_\perp/v_\parallel$	R (km)	α (degree)
A	1.5×10^5	7500	0.02	670	2.2
B	3.9×10^5	19500	0.05	1660	5.7
C	1×10^6	50000	0.1	3330	14.3

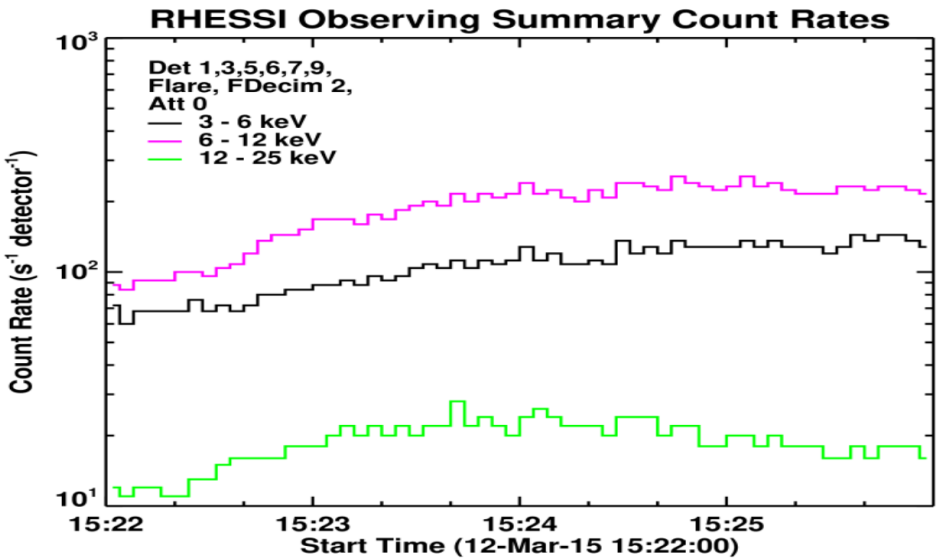
Model assumptions:

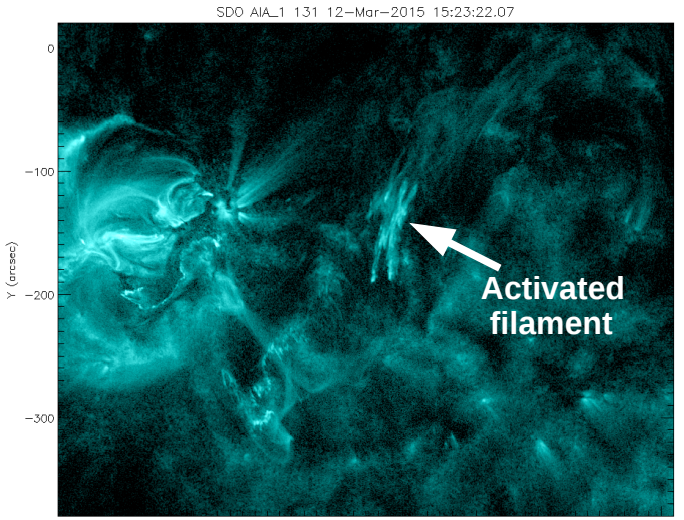
- **Gravitationally stratified solar atmosphere**
- **Cylindrical flux rope of length 210 000 km, inclined to photospheric plane with small angle α**
- **Particle beam moves downward along MF line having a helical form with radius R**
- **t=7s, $v_\parallel$=30 000 km/s**

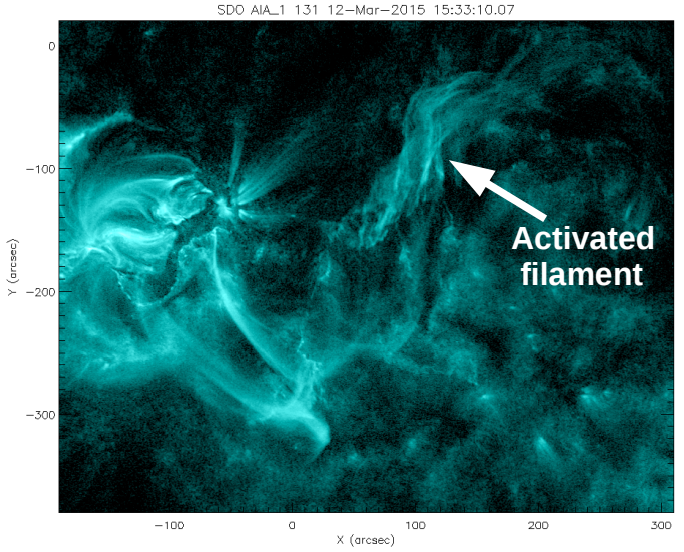
Event B - a ‚flare-like event' with the GOES SXR flux rise to the level of C-class flare

Two weak SPDBs were observed during the local peak of RHESSI HXR at 12 - 25 keV: 15:22:00 - 15:26:40 UT, at 1.0 - 1.3 GHz frequency range, with frequency drifts ~ 143 and 67 MHz/s and duration of ~ 3 and 4 s.

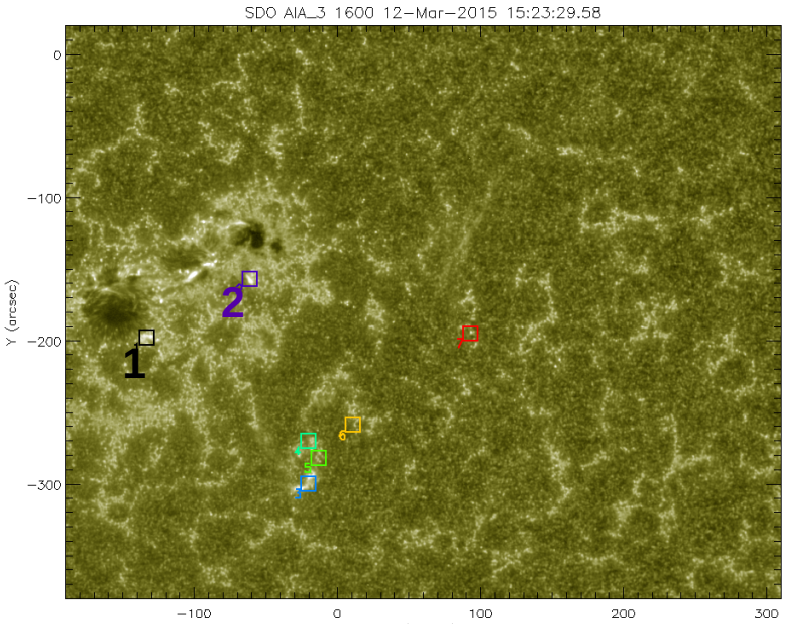


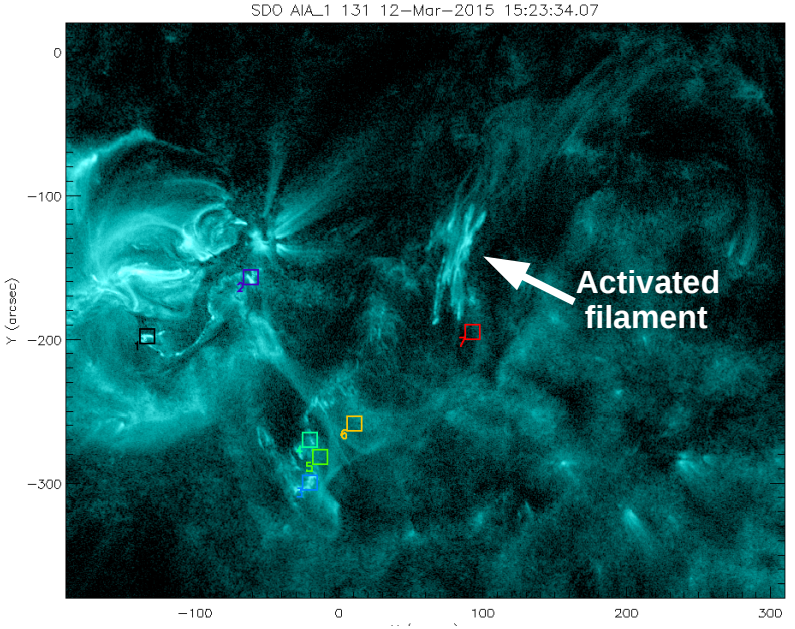


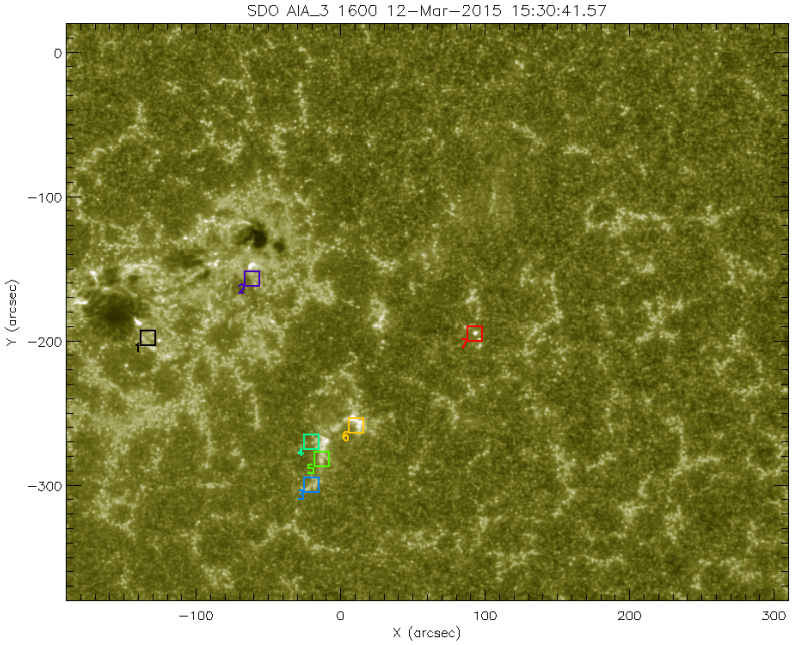


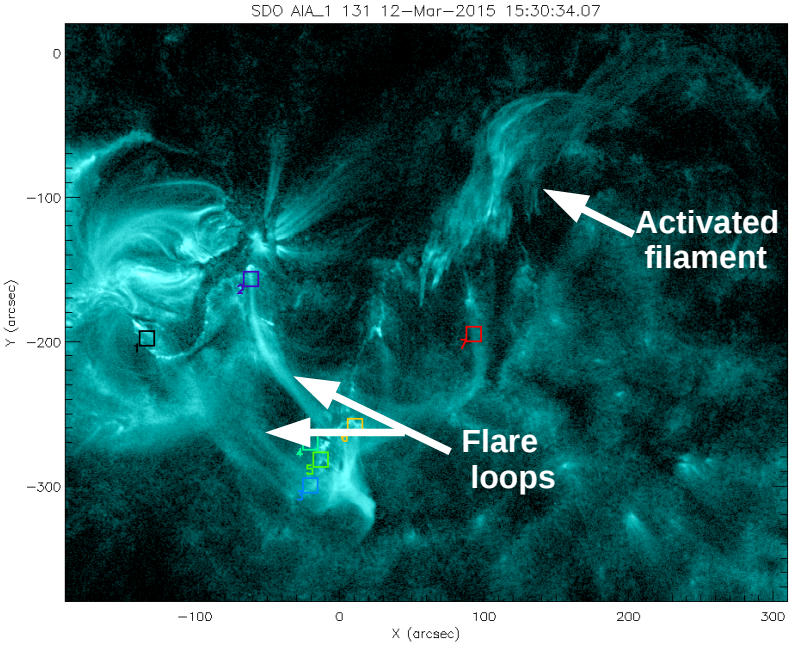


Event B – evolution in SDO/AIA UV/EUV filters





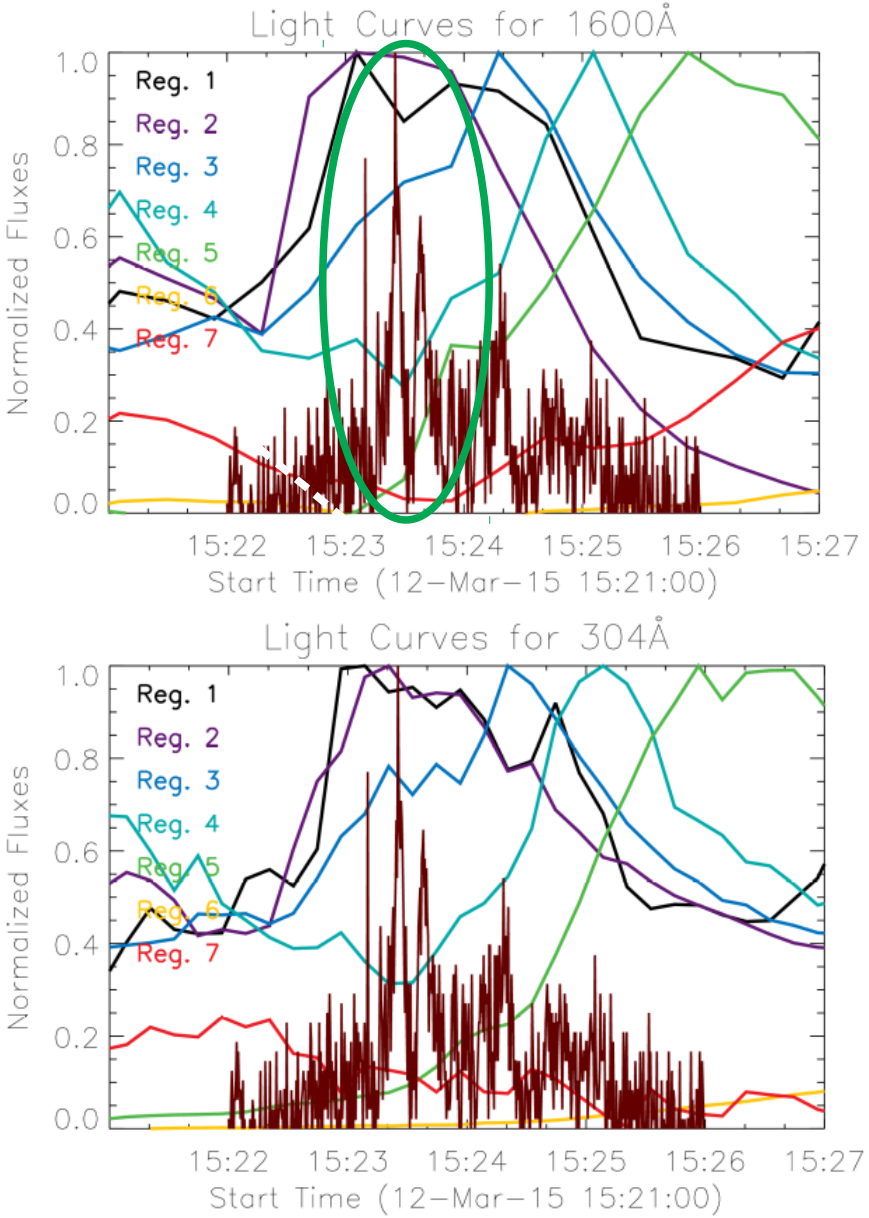




In AIA 1600A UV filter event B started by appearence of several bright regions: 1 and 2 were located within the active region and others along the magnetic field of supergranules (network).

In AIA 131 EUV we observed hot flare loops connecting regions 1 and 2 to supergranular (network) magnetic field and thier interaction with large filament.

Event B - Light Curves – from brightenings along the filament

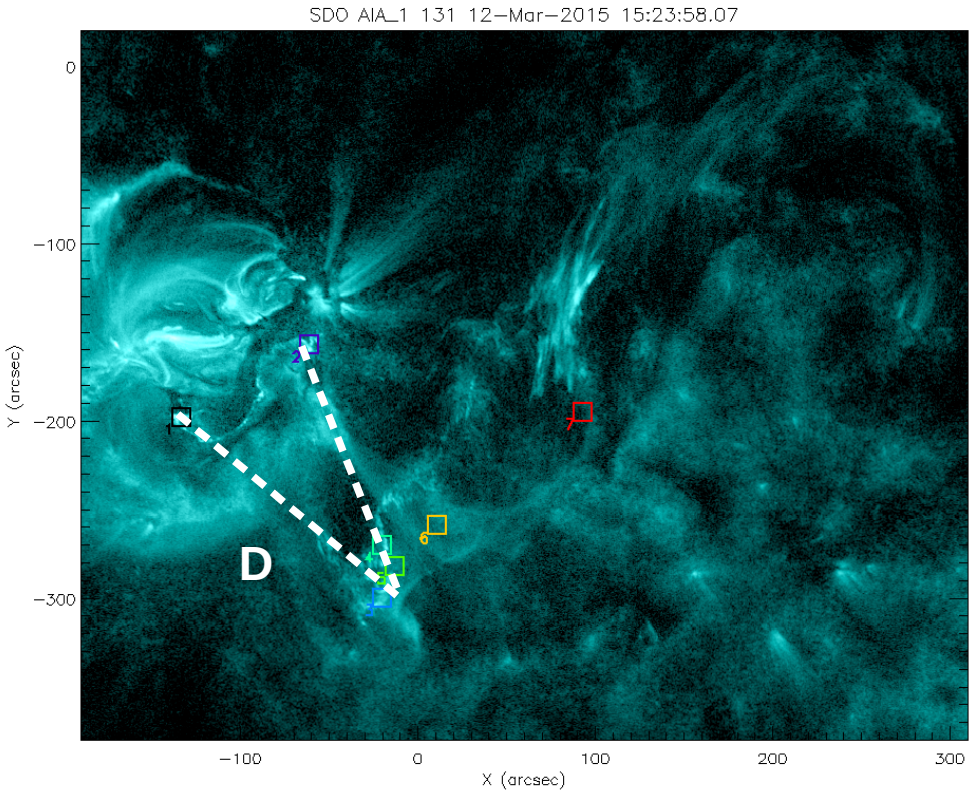


Colour coded light curves show ‚intensity (DN) time profiles‘ from regions where flare brightenings appeared

Brown curve represents radio flux at 1150 MHz and the two SPDBS occurred about 15:23:23 UT and 15:23:35 UT.

At the time when two weak SPDBs were registered, the regions 1 and 2 shows maximum ‚intensity‘. This can be due the beam of accelerated particles hitting the plasma at these regions.

Event B - The rough estimate of an agent velocity responsible for observed SPDBs



Similarly as in Event A, we consider that the beam of particles is likely propagating from a reconnection region to flare brightenings in regions 1 and 2 along horizontaly oriented magnetic field of hot flare loops (distance D).

Estimating the distance D and considering the duration 3s and 4s of the observed SPDBs, we can roughly estimate velocity of propagation:
v=38 667 km/s and v=29 000 km/s.

What we can say about observed SPDBs?

- **Duration of the observed SPDBs is several seconds:**
  Event A – Burst S ~ 7s,
  Event B – SPDBs of ~ 3s

- **Lets consider an electron beam, i.e. electrons generating bursts move in plasma with relatively high density where collisions are not negligible – stop time *(Karlický et al. 1990)*:**

- **Event A - v=30 000 km/s in plasma with mean density 2.4x10^{10} cm^{-3} for the 1st harmonic stop time for electron is ~ 0.02s < 7s !**

  Proton or neutral beam (protons and el. having the same velocity) – stop time for proton – 64.1s > 7s ! The energy of the protons in this case is ~ 4.7 MeV

- **Event B – v=38 667 km/s in plasma with mean density 1.8x10^{10} cm^{-3} for the 1st harmonic, stop time for electron is ~ 0.06s < 3s !**

  Proton or neutral beam (protons and el. having the same velocity) – stopping time for proton – 176s > 3s ! The energy of the protons in this case is ~ 7.5 MeV

Conclusion

- **The origin of SPDBs is still not very clear – the S-like shape of one SPDB gives us a hint that a beam of accelerated particles beeing an agent producing the SPDBs**
- **For both events, SPDBs appear in conncetion with initial phase of magnetic reconnection (impulsive phase of the Event A)**
- **Both events involved reconnection with the magnetic threads of nearby large filament rooted in supergranular magnetic field and small frequency drift can be due to propagation along nearly horizontaly oriented magnetic field lines**
- **Due to very short electron stop time, less than burst duration, we propose that the observed SPDBs could be produced by neutral or proton beam. This interpretation is in agreement with the works by *Benz & Simnett (1986)* and *Simnett (1995)* who explain the slowly drifting type III bursts in 230-350MHz in a similar way.**
- **We need to study more cases of SPDBs (2 more flares under the study) and the radio observations with spatial information about the source (0.8-2.0 GHz range) would be very helpful!**

References:

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- Zemanová, A.; Karlický, M.; Kašparová, J.; Dudík, J., **2020**, ApJ 905, id. 111, pp. 13, doi: 10.3847/1538-4357/abc424
- Benz, A. O. and Simnett, G. M., **1986**, Nature, 320, 508, doi: 10.1038/320508a0
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